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Introduction

Reviewing the present state of knowledge on the cycling of organic matter in the oceans, Menzel (1974) states that "virtually nothing is known of the mechanisms by which organic matter is transported to the depths and how the energy requirements of the deep sea are met." It is his opinion that this "is the single most important unresolved problem in the fields of marine biology and chemistry." Possible pathways of energy flux to the ocean sediments have been discussed (Vinogradov, 1968) but few attempts have been made to evaluate them (Weibe, Boyd and Winget, 1976). There is a similar lack of information about the organic input to the continental shelf sediments, data on which are needed for fisheries management and to estimate the rates of input of pollutants to the sediment.

Most of the available data on the rates of organic carbon input to the sediment have been collected in shallow inshore areas using sediment traps placed and retrieved by divers (Steele & Baird, 1972). The traditional type of sediment trap was an open cylinder or funnel, but recent evidence has shown a relationship between the shape of the vessel and its efficiency of collection. In general a long thin cylinder collects less material per unit area than a wider cylinder of the same length because the former produces less distortion in the water flow over the mouth of the vessel. Soutar (personal communication) has shown that a grid with cells approximately 1 cm x 1 cm x 4 cm deep to divide the open mouth of a larger collecting vessel reduces the turbulence inside the mouth. This principle was incorporated into the Aberdeen sediment trap.

The best shape for a sediment trap was discussed by participants from laboratories in the USA, Canada, Germany and the UK at the recent NATO Conference on the Benthic Boundary with a view to standardization (p 297 in Cave, 1976). Following this conference a sedimentation trap was designed at the Marine Laboratory, Aberdeen, in the form of a steep sided cone. The design used is very similar to that of traps developed by the Kiel group who participated in the Conference. A sophistication of the Kiel traps is an electronic sample changer which allows collection of a time series of samples within a single period of development. The main advantage of the simpler Aberdeen version, apart from reduced cost, is that sets of traps, five or six to a line, can be set at various depths and this has been found to be essential to differentiate between freshly settled and resuspended material.

The Aberdeen Sedimentation Trap

The trap, which is made of glass-reinforced plastic (GRP) and polyvinylchloride (PVC), is in the shape of a cone with two lateral fins for strength and stability (Fig. 1). The mouth of the cone contains a 1 cm x 1 cm x 4 cm deep grid and the cone tapers steeply and smoothly downwards to a removable bucket. Around the top of the cone is a flotation collar of Eccofloat PG30 giving the slight positive buoyancy required to maintain the trap in a vertical position. Two snap shackles serve to attach the trap to the mooring, the lower snap shackle mounted on a thin tail rope to allow for easy length adjustment.

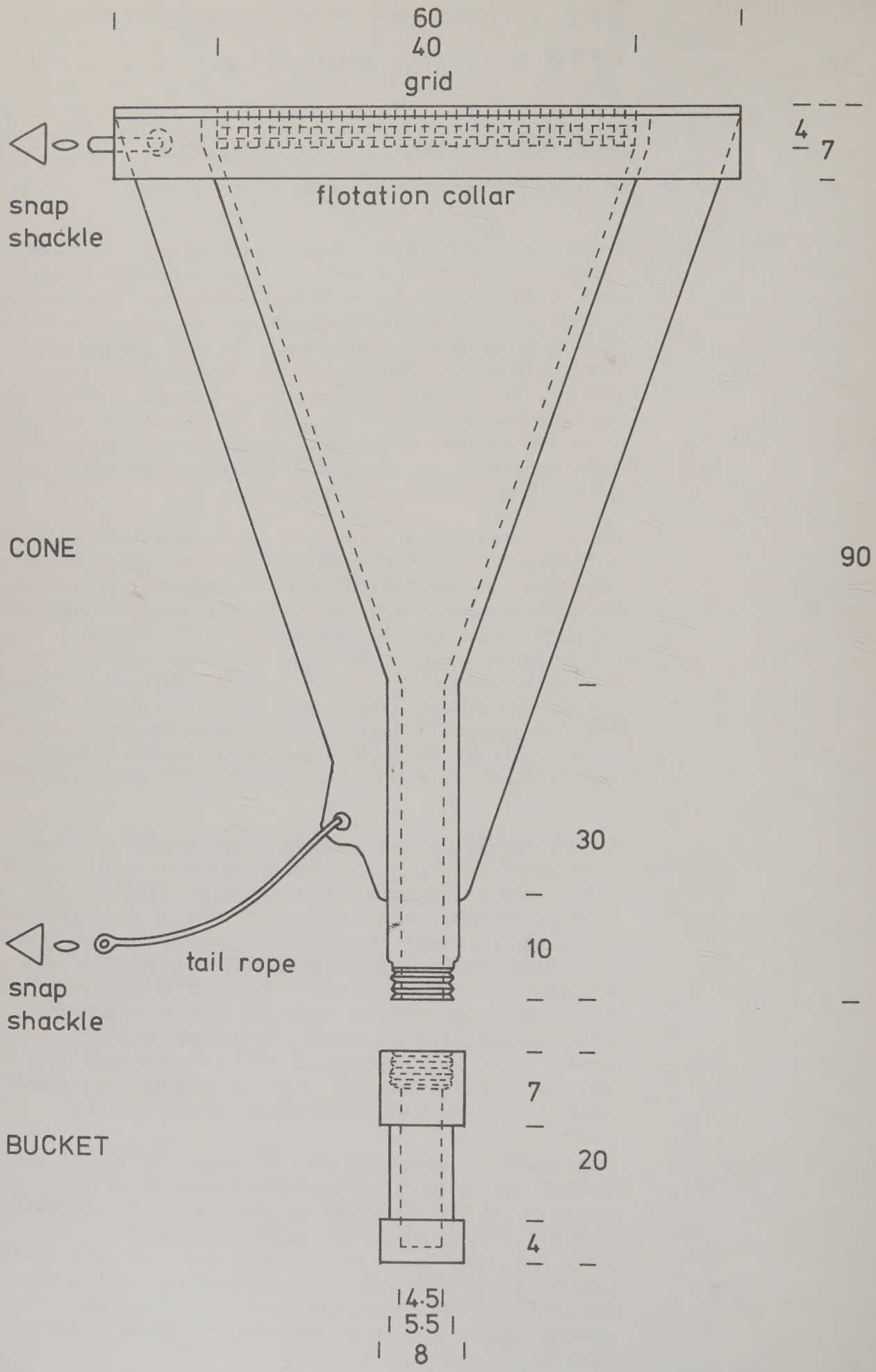

Figure 1. The Aberdeen sedimentation trap.

General Description of the Rig

The mooring is constructed of synthetic fibre rope in a 'U' configuration (Fig. 2). A pick-up rope and associated pallets lead to a subsurface buoy which can be up to 30 m below the surface holding taut a rope to which the sedimentation traps are attached. The subsurface buoy is anchored by means of a 150 kg clump of chain. A 5 kg anchor of the modified Danforth type prevents any lateral drag. A buoyant ground rope of 220 m runs from the anchor clump to a weight of 25 kg which anchors a further buoyant rope and a single surface marker.

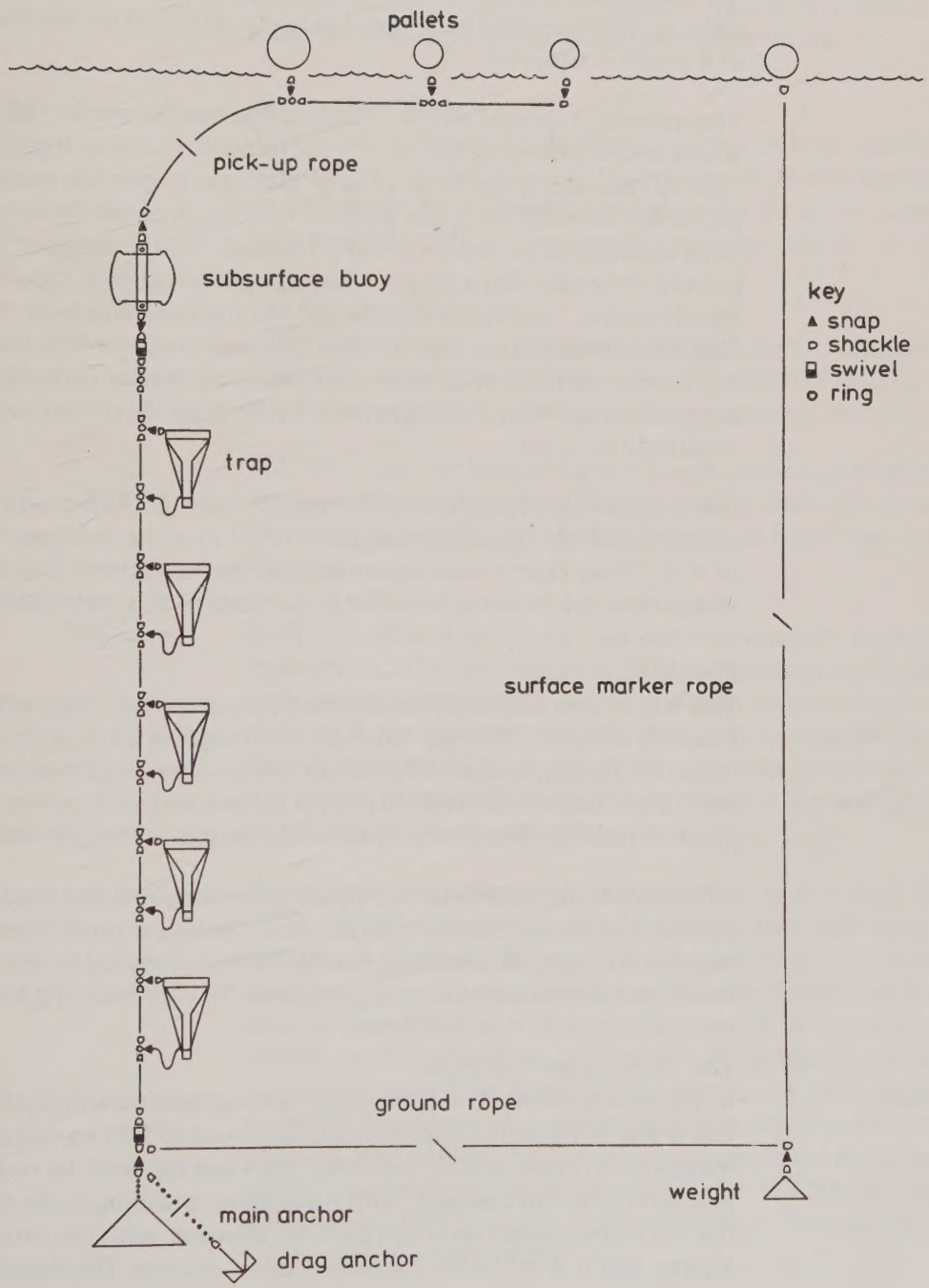

Figure 2. Sedimentation trap rig.

The Equipment

The Subsurface Buoy

This is a hollow cylinder made of GRP and is 50 cm long by 70 cm diameter built up on the ends of a liferaft housing mould. The walls are not less than 16 mm thick and the weight is 45 kg giving a net buoyancy of 90 kg. A metal frame consisting of a band of 6.35 mm mild steel plate 76 mm wide is fitted around the circumference with a lug at top and bottom for attachment to the mooring.

The normal safe working depth for these buoys is 30 m, although depth testing shows they would be safe to 100 m.

The Ropes

To meet the specifications for this rig, rope is used in preference to wire principally to allow for trace metal analysis of the sedimentation samples if desired. There is, however, a small number of metallic components which are mainly of stainless steel. In addition, rope is preferred to steel wire because it is buoyant, enabling the anchor weight to be kept low, and because it is easier to transport and handle and can be easily used on the warping barrel of a winch if required.

The material, type and size of rope was selected for use in 150 m of water with a current speed of 50 cm s^{-1}. A positively buoyant rope is ideal for the pick-up rope and it has to be of large diameter to give the necessary strength; but as the diameter increases so does the drag. A compromise was found using a computer program - SHAPE (Barber, 1971) - designed for this purpose. SHAPE indicated that a 14 mm diameter polypropylene rope met the desired specifications. The choice of rope to hold the traps was more difficult since SHAPE showed that a much thinner rope was required here than that used on the pick-up rope. With the exception of the Kevlar varieties, the only acceptable rope is of 8 mm diameter nylon Super Braidline, which is slightly negatively buoyant.

Using these ropes with five sedimentation traps, SHAPE predicted a lateral displacement for the subsurface buoy of 27 m and a downward displacement of 4 m. These figures were acceptable on the assumption that SHAPE exaggerates the mooring response to currents of this magnitude (Payne, 1975).

The Pick-up Rope

This is a 14 mm diameter, three strand polypropylene rope with a minimum breaking strain of 2790 kg. Normally the length is 90 m, ie three times the depth of the subsurface buoy, comprised of three lengths of rope, 60 m, 15 m and 15 m, handspliced with hard eyes at each end with points for the attachment of marker pallets in between these lengths and at the end.

Originally 14 mm diameter multiplait polypropylene was used primarily to avoid the unlaying process common to three strand ropes known as hockling, but the difficulty in obtaining reliable terminations led to the use of the more easily spliced three strand polypropylene. To date hockling has not occurred.

The Trap Supporting Rope

In the first moorings 8 mm diameter three strand polypropylene was used, but it was felt that its minimum breaking load of 960 kg reduced the safety margin to an unacceptably low level. This was replaced by nylon Super Braidline of 8 mm diameter with a minimum breaking strain of 1450 kg. It has the highest breaking strain per unit diameter with the exception of Kevlar, and it is attractive for several other reasons. The double construction, braid on braid, ensures that even with a completely severed outer sheath a full 50% of its strength remains. It is accurately balanced so that spinning and kinking are eliminated. In addition it is simple to splice and handle, does not creep under repeated loadings and the percentage extension under load is less than half that of conventional three strand nylon.

The hard eyes at each end are hand spliced using the technique of separating the sheath from the core and tucking one into the other.

Each trap is supported top and bottom from the connections between the rope lengths. To allow for the length of the trap each trap has its own 'trap length' of rope measuring 56 cm. From the depth of water, the number of traps and the depths at which the traps are required, the lengths between the 'trap lengths' can be calculated allowing 5% for extension under a 90 kg load.

The Tail Rope

The bottom of each trap is connected to the trap support rope by a 1 m tail rope of 6 mm diameter three strand polypropylene, with a minimum breaking strain of 550 kg. A snap shackle is spliced into one end and the tail is whipped and knotted into the eye at the bottom of the trap. This allows the tail rope to be adjusted for length as conditions dictate. In practice the length of this rope has been maintained at approximately 25 cm.

The Ground Rope

This rope has the same specification as the pick-up rope. It is necessary that the rope be buoyant to avoid chafing against the sea bed and also to provide an easy target for a towed grapnel should both sets of surface marks be missing. The length of this rope is nominally 220 m.

The Surface Marker Rope

Since this rope carries no appreciable load, 8 mm diameter three strand polypropylene with a minimum breaking strain of 960 kg is used. Its length is 1.5 times the depth which minimises undertow in strong currents.

This rope together with the ground rope provide an alternative method of recovery should the pick-up line be missing, although recovery by this method destroys the lower sedimentation samples as these traps are recovered upside down.

Hardware

Most connections on the pick-up and trap support ropes are made shackle-ring-shackle. This facilitates handling and gives an uncluttered ring for the rapid engaging and disengaging of the snap shackles on the traps. The ring is made of 9 mm diameter stainless steel with an outside diameter of 54 mm. The 'D'-type shackles are also of stainless steel with an 8 mm pin diameter and a yield point of 1526 kg. Similar shackles are used at the top of the trap and under the 76 cm circumference pallets.

To accommodate the swivels, subsurface buoy and the 1.27 m circumference pallet, the 'D'-type shackles are of stainless steel with a pin diameter of 13 mm and a yield point of 2807 kg. The drag anchor and chain are secured with galvanised steel 'D'-type shackles with a pin diameter of 9 mm. Galvanised steel 'D'-type shackles with a pin diameter of 13 mm are used on the main anchor, on the ground rope and on the 25 kg weight. All shackles are seized with monel wire. Two types of snap shackle are used on the rig. Attached to the traps and pallets are stainless steel snap shackles 92 mm in length with a breaking load of 2267 kg. Securing the subsurface buoy, main anchor and weight are manganese bronze snap shackles 133 mm in length with a safe working load (SWL) of 1 t. The swivels are of the stainless steel ball-race type and have a SWL of 3 t.

Stainless steel thimbles are used in the hard eyes of the pick-up rope and the trap support ropes. Originally nylon thimbles were used but these suffered severe distortion under strain. Galvanised steel thimbles suffice for the hard eyes of the ground rope and surface marker rope.

The main anchor weighs 150 kg and consists of three lengths of used stud-link cable linked together by 2 m of 9.5 mm chain. The galvanised steel drag anchor is a 5 kg Meon Mk 7 joined to the main anchor by 10 m of 9.5 mm galvanised steel open link chain. The 25 kg weight is made of square section steel with an loop welded to the top as the point of attachment.

The Pallets

Three pallets are attached to the pick-up rope, one of 1.27 m circumference and two of 76 cm circumference. There is one pallet of 1.0 m circumference on the surface marker rope.

Installation and Recovery

Preparations for shooting from a Side Trawler

A rope messenger is run onto the main barrel of the winch followed by the rig commencing at the surface end of the pick-up rope. All shackles and swivels are on the ropes which are disconnected on shooting to insert the subsurface buoy. Shackles and swivels are, wherever possible, kept to one side of the barrel. A large snatch block with a 200 mm throat is positioned directly in front of the winch and at right angles to a similar block hanging from the derrick (Fig. 3). This block is positioned to give a vertical lead just clear of the starboard side of the ship. The end of the trap support rope is run through these blocks and brought back inboard where the anchor and drag anchor with its chain are snapped on. The snap shackles are attached to the subsurface buoy and it is positioned together with the three pick-up pallets under the derrick. The surface marker rope with its pallet is coiled loosely aft together with the ground rope. The 25 kg weight is snapped on, the surface and ground ropes are joined and the other end of the ground rope is shackled into the main rig just above the anchor. A short chain stopper with a Karabiner in the tail is shackled into the rail under the derrick. The sedimentation traps are placed forward near the derrick. Finally the position and depth are checked.

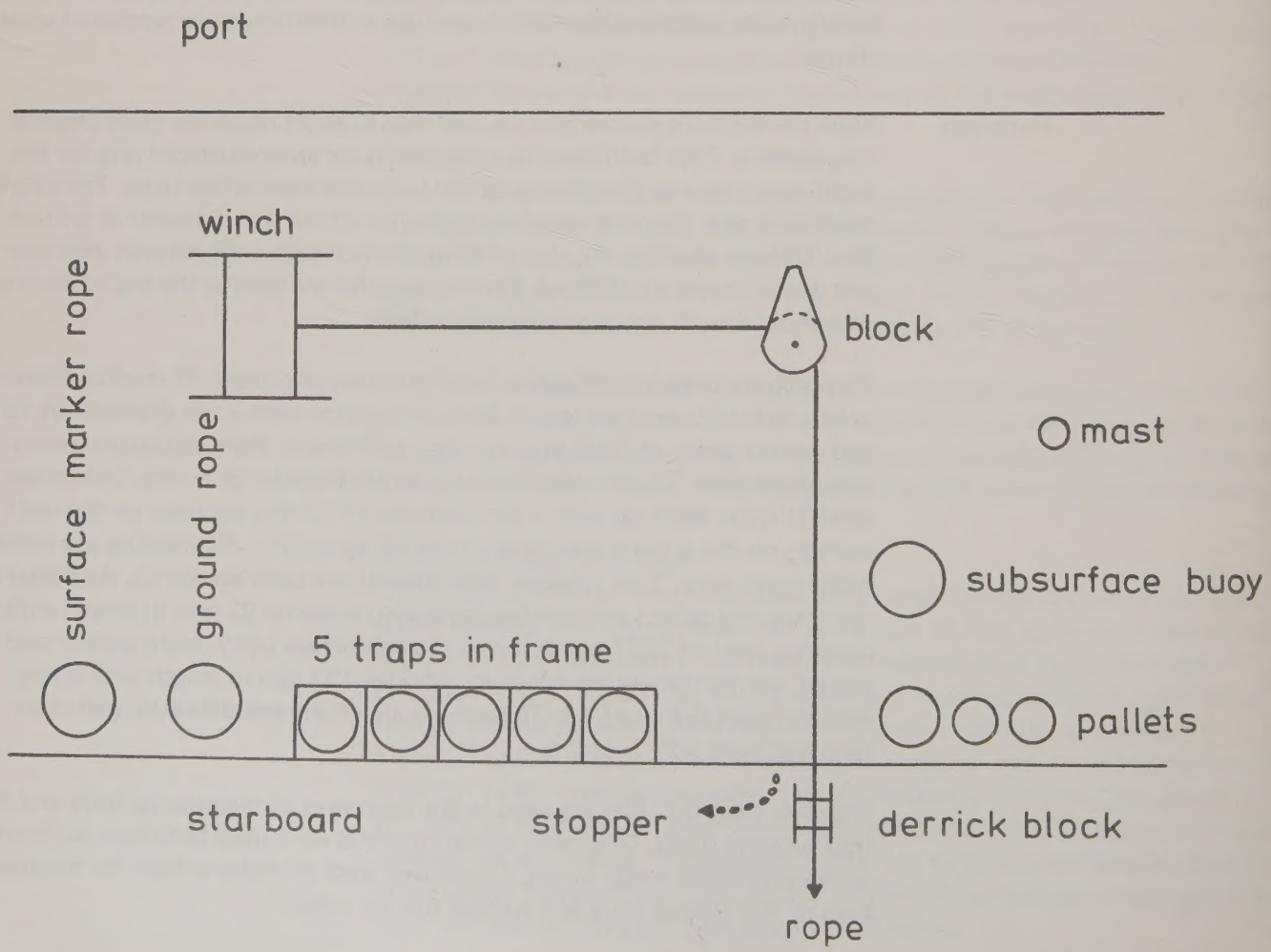

Figure 3. Diagram of deck lay-out.

Shooting

The ship turns with its starboard side to the wind or tide and stops. The anchors are lifted over the side and the 25 kg weight is dropped overboard pulling with it nearly all the surface marker rope and the ground rope. A Decca position is taken when the weight reaches the bottom and the ship then drifts down wind or tide pulling out the remainder of the ropes. The anchors are then lowered stopping with the first 'trap length' above the anchor at the level of the rail. A sedimentation trap is lifted by hand and the two snap shackles engaged in the rings at each end of the 'trap length'. This procedure is repeated until all the traps have been installed. The rope is then lowered until the chain stopper can be snapped into the rig below the swivel. The chain stopper is made to take the strain, the rig is broken above the swivel and the free end brought inboard and connected to the top of the subsurface buoy. Using the pick-up rope the buoy is lifted over the rail and the snap shackle underneath is engaged with the main rope above the stopper. The winch takes the strain, the stopper is disengaged and the rest of the rig is swiftly paid out. A Decca position is taken as the rope goes slack and the appropriate pallets are snapped in as the connections pass the rail. The messenger is unshackled and, with the release of the final pallet, the entire rig is in position. Alternatively the mooring may be deployed in a similar manner to that described by Payne (1975).

Preparations for hauling

The deck layout is similar to that for shooting. The end of the rope messenger is run through the blocks and is made ready amidships. A frame to hold the sedimentation traps in a vertical position to drain is brought forward to the rails. Grapnels are made ready on the starboard side.

Hauling

The ship moves upwind or tide and a grapnel is thrown across the pick-up rope between the two smaller pallets. The end is brought aboard, the pallet unsnapped and the messenger is shackled to the pick-up rope. The winch hauls in the slack and the pallets are taken off as they pass the ship's rail. Using the chain stopper the rig is secured under the subsurface buoy which is disconnected from the rig at the snap shackle underneath it and lifted inboard using the pick-up rope. The buoy is removed and the pick-up rope is shackled into the trap support rope at the stopper. The winch takes the strain, the stopper is disconnected and hauling begins again. As each trap breaks the surface it tips slightly to the extent of its tail rope and approximately 50% of the water in the upper cone is spilled. Some traps are fitted with a drain and these are held at the rail until they have emptied. The snap shackles are undone and, taking care to keep the trap reasonably vertical it is lifted over the rail and placed in the frame. The bucket is loosened slightly to allow further draining. The rest of the traps are recovered in a similar manner. Following the traps is the main anchor which is brought inboard and unsnapped. The ground line is then run onto the winch until the 25 kg weight can be recovered. The weight is unsnapped and the surface marker rope is hauled aboard. With the recovery of the surface marker pallet, hauling is complete.

Performance

This type of sedimentation rig has been moored in Sullom Voe, Shetland, in a depth of 40 m, in various Scottish sea lochs at depths of 20 to 65 m, and on the Fladen Ground in the North Sea at depths of 100 - 150 m.

The rig has been handled by vessels of 23 m to 64 m in length both over the side and over the stern. It has been winched on the main winch barrel and on the warping barrel and over a derrick and through a trawl gallows. It has been deployed anchor first and anchor last. Handling in rough seas has been exciting but always successful.

Inspection by divers confirmed that the traps remain vertical in the water and that they are unaffected by the wire angle within the limits of the length of the tail rope. There were some doubts that pallets alone provided a sufficiently good surface marker but experience has shown that they are adequate. It is likely, however, that a dhan buoy will be added to the rig, or installed near the rig for future moorings in the open sea. Some trouble was experienced with the ropes chafing in the blocks but a simple modification of the checker and chafer plates can cure this problem. There has been no evidence of the anchor or weight dragging in rough weather.

During the Fladen Experiment of 1976 (FLEX 76) the sedimentation rig was deployed and recovered successfully 13 times over a period of two months. One rig which was inadvertently laid very close to the path of a pipe-laying barge was lost although the subsurface buoy was recovered adrift subsequently. It is not known whether this loss was due to failure of the mooring, interference by the pipe-laying barge, or some other extraneous cause.

The data from the sedimentation traps used during FLEX demonstrated the need for a string of collectors situated at various depths above the bottom. Two examples (Table I, Fig. 4) show two of the problems encountered in interpreting the data. The set of traps deployed 2, 12, 33, 66 and 100 m above bottom during April 1976 show the influence of resuspended material in the bottom two traps. On the basis of microscopic analysis the composition of the material collected showed a high proportion (25-30%) of inorganic material in the bottom two traps. In later collections, eg 23-28 May 1976, large numbers of zooplankton were collected in traps situated in the upper parts of the water column and this made the collections useless for estimation of organic input to the bottom. Microscopic analysis showed little influence from resuspension in the bottom three traps during this period so the values can be used directly to estimate the organic input to the bottom.

Table I

Percentage composition of sedimentation samples, 1976

	16-23 April					23-28 May				
Metres above bottom	2	12	33	66	100	2	12	45	70	92
Faecal pellets	3	3	5	41	36	8	20	6	8	10
Phytodetritus	64	69	85	54	53	84	73	92	84	10
Crustacean remains	<1	<1	1	1	6	2	1	1	7	79
Sand grains	30	25	7	2	0	5	5	0	0	0
Diatoms	2	2	2	2	5	1	1	1	1	1

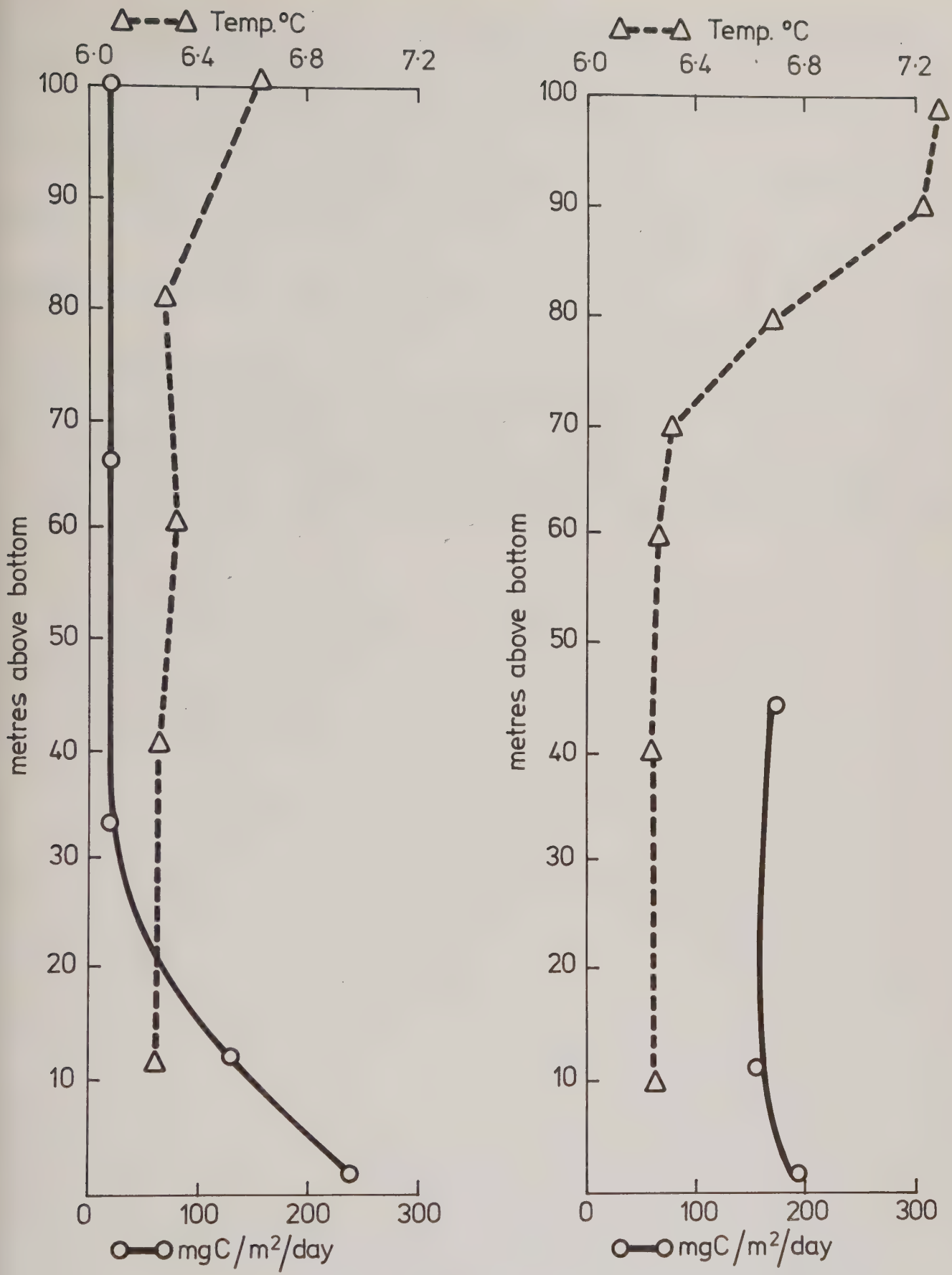

Figure 4. The amount of organic carbon collected per square metre per day plotted against the depth, showing two typical profiles during the spring bloom in 1976.

Future development

To overcome the difficulties of shooting the rig under strain the technique of installing the rig anchor last will be further developed. To avoid recovering the rig under the strain of the anchor weight an acoustic release is to be incorporated above the anchor. The 'U' configuration, however, will be maintained using the surface marker rope and ground rope to recover the anchor after the release has been fired and the main rig hauled. Since these rigs are normally recovered every three days, economy dictates that the anchors should be recovered. This short deployment period gives little choice in the type of acoustic release to be used as the release has to have a simple and inexpensive rearming method.

In due course a single-anchor sedimentation rig will be developed for deployment in water of depth greater than 400 m.

Summary

The factors influencing the design and deployment of sedimentation traps are discussed. Sedimentation traps used by the Marine Laboratory in the North Sea are described in detail. The methods used for their deployment and recovery on different research vessels is outlined. Some data collected during the spring of 1976 are presented to illustrate the difficulties in interpreting the results from these traps. The necessity of using a string of five or six traps on one line at various depths is demonstrated.

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